

Time Series of O₃ profiles from ground-based FTS at Mauna Loa, Hawaii and Thule, Greenland compared to O₃ from Aura

James Hannigan, Rebecca Batchelor and Michael Coffey
NCAR
corres. auth.: jamesw@ucar.edu

Advances in retrieval techniques and harmonization of retrieval parameters have enhanced the information content and improved the consistency of Fourier transform infrared (FTIR) spectroscopic measurements made at Network for the Detection of Atmospheric Composition Change (NDACC) stations around the world. The NDACC FTIR community now archives retrieved profiles for a minimum of 10 trace species from 19 sites, providing a more comprehensive, long-term, global data set to the satellite and modeling communities. In this presentation, retrievals of O₃ from the tropical Mauna Loa observatory (19.54°N, 155.57°W) and the polar Thule observatory (76.53°N, 68.74°W) are presented and compared with O₃ measurements from the full range of Aura instruments (MLS, HIRDLS, OMI and TES). Typical information content of the ground-based measurements range from approximately 3.5 degrees of freedom for signal at Mauna Loa, to nearly 7 near the Pole, and include sensitivity from the ground to approximately 40 km. Long time series from these sites (10 years at Thule & 15 years at Mauna Loa) are typical for NDACC station records and provide a bridging mechanism between satellite missions.

Introduction

Three primary missions of the NDACC are "Detecting trends in overall atmospheric composition and understanding their impacts on the stratosphere and troposphere", "Studying atmospheric composition variability at inter-annual and longer timescales" and "Calibrating and validating space-based measurements of the atmosphere". Here we compare, calibrate and extend the O₃ measured by the 4 Aura sensors at two NDACC sites in the northern subtropics and the Arctic using coincident O₃ profiles measured there by ground-based Fourier Transform Spectrometers. The Arctic site is the Thule Air Base (TAB) and the subtropical site is the Mauna Loa Observatory (MLO).

Aura Datasets & Coincidence Criteria

The Aura data used are:

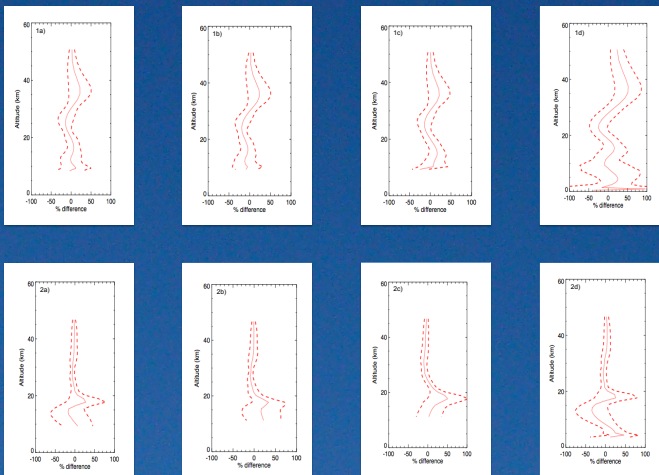
HIRDLS: L2_v05
MLS: L2GP_O3_v2.2
TES: L2-O3-Nadir-F06_07
OMI: L2OVP_OMO3PR

The coincidence selection criteria are:

Lat / Lon box (MLS, HIRDLS, TES): +/- 5 latitude, +/- 8 longitude
Distance (OMI): 150 km (these data files were pre-made for TAB/MLO)
Time Separation: maximum of 5 hours

Comparison of Profiles

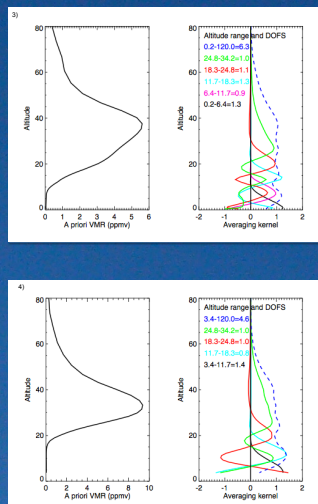
Figure 1 a-d shows the mean percentage difference and standard deviations of O₃ vertical profiles (Aura Sensor+FTIR0.5/Aura Sensor+FTIR) for MLS, HIRDLS, OMI and TES at TAB. Figure 2 a-d is the same for MLO. For these comparisons the satellite instrument profiles have been smoothed by the averaging kernels of the FTIR following Rogers & Connor 2003, though note that OMI and TES may, in fact, have less information than the ground-based spectrometers. At TAB, the tropopause is typically at approximately 30 km, below the altitude range of most of the satellites. Good agreement is seen throughout the stratosphere, though a positive bias in the FTIR profiles is seen near the ozone peak, around 35 km, and a correspondingly lower bias is seen in the lower stratosphere at approximately 25 km. The Mauna Loa profiles agree well through the stratosphere, however show a pronounced bias at approximately 18 km. This is likely a result of the limited vertical resolution causing smoothing across the tropopause.



Figures 1 and 2. a-d: Mean (solid) +/- one standard deviation (dotted) of profile differences for MLS, HIRDLS, OMI and TES for TAB (1-top row) and MLO (2-bottom row). Differences have been determined using (Satellite-FTIR)/0.5(Satellite+FTIR) * 100, where Satellite is the Aura sensor O₃ profile, smoothed using the FTIR averaging kernel and a priori. The altitude range represents the region with both satellite data and FTIR sensitivity greater than 0.5. Measurements cover the time period where both instruments have measurements.

FTS Retrievals

Retrievals are performed using the SFIT2 implementation of the optimal estimation technique. A discussion of the measurements and retrievals is given in Hannigan et al. 2009 for TAB and is similar for MLO. The retrieval parameters for each gas within the NDACC are largely homogeneous, given the variation in latitude and altitude of the various sites. The characterization of the O₃ retrieval is shown by the a priori profile and averaging kernels shown in Figures 3 & 4 for TAB and MLO respectively. Typical averaging kernels are shown for selected summed layers and the total column. Degrees of freedom for signal (DOFS) are also given for each layer. Note that the ground-based FTS has good sensitivity to O₃ in the troposphere.



Long term record

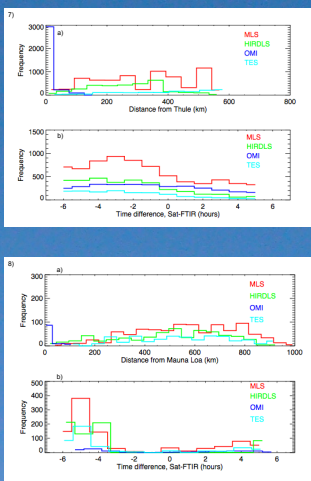
Figures 5 and 6 are long term records (1999-present for TAB, Figure 5, and 1995-present for MLO, Figure 6) from the ground-based instruments showing mean volume mixing ratio (VMR) in selected layers. These layers have been selected to provide DOFS > 1 in the FTIR profiles. The FTIR measurements have been overlaid by an approximation of what each of the Aura sensors would have measured over this time period, based on the comparisons above. The center of each bar is determined from the mean bias in this column over the AURA time period, with error bars indicating +/- 1 standard deviation, as detailed in Table 1.

Altitude range	Typical DOFS	MLS Mean diff +/- 1 std dev (%)	HIRDLS Mean diff +/- 1 std dev (%)	OMI Mean diff +/- 1 std dev (%)	TES Mean diff +/- 1 std dev (%)
TAB					
0.2-4.4	0.9	n/a	n/a	n/a	11.6 +/- 58.9
6.4-11.7	1.3	n/a	n/a	n/a	-5.9 +/- 25.4
11.7-18.3	1.3	3.8 +/- 12.4	-7.1 +/- 13.1	12.7 +/- 12.7	10.0 +/- 23.0
18.3-24.8	1.1	-7.3 +/- 8.7	-18.9 +/- 9.0	-8.7 +/- 11.1	-18.5 +/- 17.7
24.8-34.2	1.0	-2.6 +/- 13.3	-2.8 +/- 12.0	-2.3 +/- 12.9	12.9 +/- 23.3
MLO					
3.4-11.7	1.4	n/a	n/a	n/a	6.7 +/- 20.5
11.7-18.3	0.8	4.8 +/- 35.7	25.8 +/- 37.5	33.3 +/- 37.8	-2.5 +/- 31.0
18.3-24.8	1.0	-1.1 +/- 10.2	-1.2 +/- 10.2	-1.2 +/- 10.2	-6.7 +/- 7.7
24.8-34.2	1.0	-5.7 +/- 5.1	-7.0 +/- 5.2	-3.4 +/- 7.1	-3.2 +/- 6.8

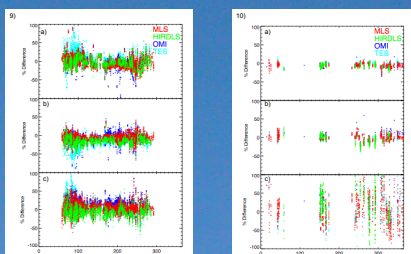
Table 1: Mean difference and standard deviation in the average VMR in the quoted columns, between Aura instruments and FTIR. Differences are determined as described above. Note that statistics in the lower layers are limited by the AURA instrument sensitivity in the lowermost atmosphere.

Figures 5 and 6, in addition to providing a representation of the expanded satellite time series, show several interesting features. In the Arctic, the middle layers (11-18 & 18-24 km) clearly show the Brewer-Obsson (B-O) circulation build up of winter O₃, while the upper and lower layers are independent. The 6-11 km layer has some signature as the tropopause (typically at ~8 km) is traversed by this layer. The large TES variability on the lowest 2 layers is due to decreased sensitivity of TES in the region, possibly attributed to Arctic snow cover and albedo effects. The large positive bias of OMI in the 18-24 km region is still being investigated. Typical tropopause altitudes at MLO are ~18 km so the two lowest layers represent independent measures of the lower and upper tropospheric O₃.

Future Work: Including more NDACC sites will create a clearer global picture and enhance our identification of trends and changes in B-O winter buildup of O₃.



Figures 7 and 8: Frequency versus distance (a) and time (b) for the compared profiles contributing to statistics provided in Figures 1 and 2 and Table 1 for TAB (Figure 7) and MLO (Figure 8). The advantage of the polar site for satellite validation is clear in the very large number of measurements passing close by and within the +/- 6 hour window.



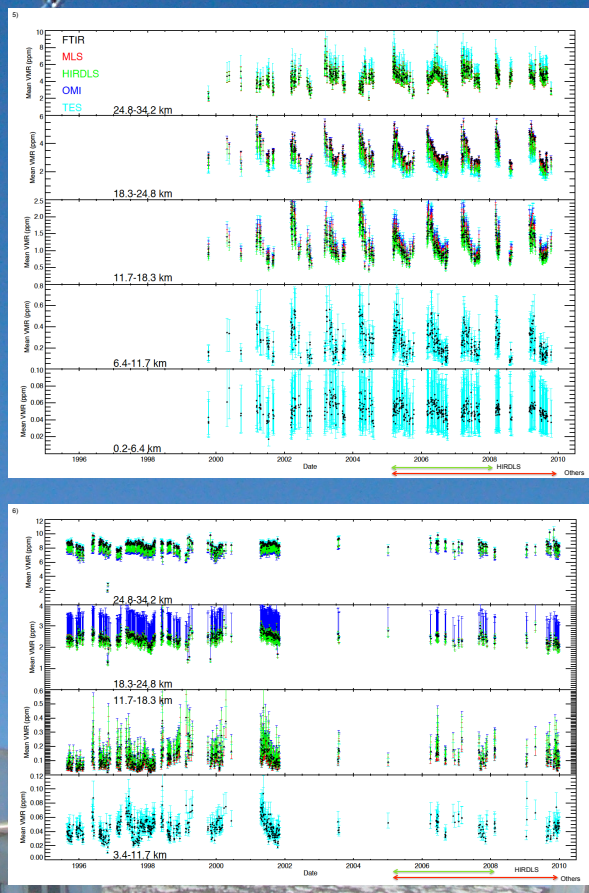
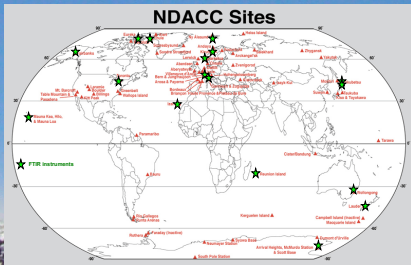
Figures 9 and 10. a-c: % differences (AURA-FTIR0.5/AURA+FTIR) as a function of day of year for 24.8-34.2 km (a), 18.3-24.8 km (b) and 11.7-18.3 km (c) at TAB (Figure 9) and MLO (Figure 10). At TAB, the greatest variability is observed in the highly variable spring. This may be improved by tightening coincidence criteria near the polar vortex. At MLO, there is little seasonal variability, though considerable scatter is seen in the lower layer, likely due to smoothing across the tropopause.

Conclusions

Ozone measurements from ground-based FTIR spectrometers contain sufficient profile information to provide a useful validation tool for satellite profile measurements. The long time series provided by these instruments additionally allows an extension of the satellite record to be determined, serving as a bridge between time-separated satellite missions. The TAB data set is a high-quality record well capturing the seasonal variability in ozone which is observed in the polar regions. The high frequency of satellite coincidences at this site makes it an ideal validation tool. The Mauna Loa data set, though slightly patchy, is the longest tropical FTIR record, providing a useful record in the under-instrumented Pacific. The MLO instrument is currently undergoing an upgrade which is expected to considerably enhance the quality of this time series into the future.

References

Hannigan, J. W., Coffey, M. T., Goldman, A.: Semiautonomous FTS Observation System for Remote Sensing of Stratospheric and Tropospheric Gases. *J. Atmos. Oceanic Technol.*, **26**, 1814-1828, 2009.
Rogers, G. and Connor, B.: Intercomparison of remote sounding instruments. *J. Geophys. Res.*, **106**, 4195-4223, 2003.



Acknowledgements. The National Center for Atmospheric Research is supported by the National Science Foundation. The NCAR FTS observation program at Thule, GR and at MLO, HI is supported under contract by the National Aeronautics and Space Administration (NASA). This work is also supported by the NSF Office of Polar Programs (OPP). We wish to thank the Danish Meteorological Institute for support at the Thule site. TES data were obtained from the NASA Langley Research Center Atmospheric Sciences Data Center. All other data was obtained from the Aura Validation Data Center.